Introduction of Hydrogen to Natural Gas Stream: Impact on Residential Appliances

James Vigen and Iren Kletsky, Gas Standards and Commodities

Introducing hydrogen into the natural gas stream will have benefits and drawbacks. Replacing some percentage of methane with hydrogen will result in emissions reduction benefits, at the expense of the performance of residential appliances that were built to efficiently combust natural gas. The purpose of this paper is to lay out those benefits and drawbacks at different levels of hydrogen mixing. In addition, we will investigate the effects of hydrogen mixtures on the operation of a wide range of household appliances and offer insights on any restrictions to their operation. This paper has drawn from multiple studies, without access to the larger hydrogen research ongoing at places such as GTI and the Department of Energy.

Natural gas appliances are designed to combust methane completely and efficiently. Introducing a new gas to this environment will affect how the gas combusts. The first aspect of this is that hydrogen produces much less heat due to its lower density (Zhao & McDonell, pp. 4-5). In the same vein, due to its physical characteristics hydrogen produces a faster flame speed relative to methane, which affects its heating characteristics. These gases can be compared based on their Wobbe Index values, which is a measure of heat output (Zhao & McDonell, p. 5).

$$Wobbe\ Index = \frac{Higher\ Heating\ Value}{\sqrt{Fuel\ Specific\ Gravity}}$$

The Wobbe Index values for methane are 51.9 MJ/M^3 and for hydrogen 48.5 MJ/M^3, which we can see are fairly similar. Replacing some percentage of pipeline gas with hydrogen won't heavily affect that gas' heating capabilities. This can be seen in practical experimentation that showed adding hydrogen does not affect cooking efficiency heavily. In Fact, going from 0% hydrogen to 50% hydrogen resulted in an increase of 9% cooking efficiency (Zhao & McDonell, p. 9).

In one study referenced, all stovetop burners were of the "self-aspirating" type. We know the lower flammability limit of natural gas is 4%, and the studied burner contained 18% gas in the burner head (Zhao & McDonell, p. 3). This fuel rich environment keeps the flame from propagating back into the burner head. Introducing hydrogen can alter the combustion characteristics of this environment, as hydrogen has a flammability range of 4% to 75% (Zhao & McDonell, p. 3). Although hydrogen's density and burning velocity does not affect cooking speed, it can affect the operation of appliances. The laminar burning velocity of hydrogen is 6 times higher than that of methane-air flames (Slim, p. 5). This speed is highly related to flame stability, and at high levels flashback can due to the speed of the flame and the flammability of the gas inside the burner head. Flashback occurs when the flame speed exceeds the unburned gas velocity (De Vries, Florisson, & Tiekstra, p. 6). This aspect of flashback is only critical in fuel-rich appliances such as cooktop burners, and not as much of a problem in fuel-lean appliances such as boilers (De Vries, Florisson, & Tiekstra, p. 11). Because of this tendency, flashback is seen as the critical factor in determining H_2^{MAX} for existing residential appliances. Practical tests of this shows that anything above a 20% hydrogen mix leads to flashback risks on cooktop burners, with some risk between 15% and 20% (Zhao & McDonell, p. 7).

Other studies have shown that up to 28% of hydrogen can be added safely and used in properly maintained household appliances (Melania, Antonia, & Penev, p. 15). All of these studies have been done with the expectation that the appliances are operating within their normal limits. If hydrogen was added to the full system one has to expect many appliances to not be maintained and operating at their safety limits, which is a consideration and would need to be researched.

The drawbacks of lower efficiency and difficulties of adding hydrogen to the natural gas stream should be countered by the emissions reductions achieved, otherwise the effort would not be worth the expense. The expected result of hydrogen addition would be lower carbon based emissions due to the lower carbon amount in the combustion process. We also expect higher NO_x emissions because of higher combustion temperature, explained by the Zeldovich mechanism (Turns). Experimentation has found the expected drop in carbon based emissions, coupled with an unexpected drop in NO_x emissions (Zhao & McDonell, p. 13). The main benefit that would come from hydrogen additions to the natural gas stream would be if the hydrogen used was produced from biomass, or excess renewable power (Melania, Antonia, & Penev, p. 34)

The main risks to hydrogen introduction in fuel-rich residential appliances can be summarized on this table:

Feature	Possible Issues
Flame Temperature	Flame burns hotter, can lead to uneven heat transfer and premature material degradation
Flame Speed	Can lead to flame stability issues, ignition problems
Flammability Range	H_2 portion can ignite prematurely and reach pockets of fuel/air mixture

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Hydrogen injection into the natural gas stream can be a step in the right direction to reduce emissions tied directly to the production, transportation, and use of natural gas. The research cited in this paper and ongoing in many other places has shown that existing infrastructure can support some percentage of hydrogen without negatively affecting residential natural gas appliances. With adjustments and future appliances being designed with this addition in mind, higher percentages would be able to be achieved safely.

References

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